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The effects of flexor pronator mass fatigue on medial elbow stability

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THE EFFECTS OF FLEXOR PRONATOR MASS FATIGUE ON MEDIAL ELBOW STABILITY

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APPROVAL OF THESIS/DISSERTATION

We, the faculty supervising the work of Nathaniel Harvey Millard, affirm that the thesis, The Effects of Flexor Pronator Mass Fatigue on Medial Elbow Stability, meets the high academic standards for original scholarship and creative work established by the Master's of Athletic Training Program and the Marshall University School of Kinesiology. This work also conforms to the editorial standards of our discipline and the Graduate College of Marshall University. With our signatures, we approve the manuscript for publication.

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ABSTRACT

Introduction: The medial elbow is supported from valgus loading with the ulnar collateral ligament (UCL), the flexor pronator mass (FPM), and the radial head. Fatigue of muscle can lead to a decrease in force production. The decrease in force production can lead to a decrease in joint stability. This study tested the effect of fatigue of the FPM muscles on the width of the medial joint space.

Methods: Thirty-one participants volunteered for this study (18 female and 12 male, 1 excluded; mean height 170.2±10.1 cm, mean weight 71.2±15.6 kg, mean age 21.53±1.87 years old). Ultrasound images of the width of the medial joint space of the non-dominant left elbow of right handed participants were collected while unstressed and during valgus loading; images were collected prior to and immediately following a wrist flexor exercise fatigue protocol. The fatigue protocol consisted of three sets of thirty wrist flexion repetitions using a blue Theraband™. Paired t-tests were conducted to assess muscle fatigue within wrist flexion and extension, grip strength, and participants' perceived exertion. A two way repeated measures design, stress by fatigue was used to assess the effect of FPM fatigue on medial elbow width during valgus loading.

Results: The wrist flexion strength measured decreased (7.5%) from an average of 22.6±7.7 lbs. to 20.9±8.3 lbs. after the fatigue protocol ($t=3.840$; $p=0.001$). Increases in perceived exertion after each set of thirty repetitions was not statistically significant ($t=1.928$; $p=0.064$). The medial elbow width increased between unstressed (2.8±0.1 mm) and stressed (3.6±0.1 mm) conditions ($p<0.001$). The pre-fatigue versus post-fatigue measures increased 0.1±0.1 mm ($p=0.011$). The stress by fatigue interaction was significant ($p=0.048$); the medial elbow width increased post-

fatigue during the stressed condition (0.2±0.1mm), while the width of the medial joint space remained unchanged in the unstressed condition.

Discussion: The fatigue protocol achieved FPM fatigue, evidenced by the 7.5% decrease in the wrist flexor strength. Following the fatigue protocol there was a greater increase in the width of the medial joint space with the applied valgus stress. This research establishes the significance of FPM fatigue on width of the medial joint space under valgus loads. Further research should be conducted to identify the effect of FPM fatigue following throwing.

CHAPTER 1

INTRODUCTION

Background

The prevalence of elbow injury is high in the overhead throwing sports, (Tagliafico, Bignotti, & Martinoli, 2015). The overhead throwing motion produces a large valgus force at the elbow. This valgus force must be resisted by the flexor pronator mass (FPM, active stabilizer) and ulnar collateral ligament (UCL, passive stabilizer) structures of the medial elbow. Repetitive loading of the medial structures of the elbow can lead to an increase in medial elbow instability (Fleisig, Andrews, Dillman, & Escamilla, 1995). Medial elbow instability has been linked to a greater risk of elbow pain (Kane, Lynch, & Taylor, 2014). Therefore the influence of the FPM contribution as the primary active stabilizer to medial elbow stability needed to be further explored.

The elbow is a hinge joint, made up of the humerus, radius, and the ulna. The primary ligaments supporting the elbow are the UCL, the radial collateral ligament, and the annular ligament (Davidson, Pink, Perry, & Jobe, 1995). The UCL provides passive medial support, against the valgus force (Davidson et al., 1995), while the FPM provides active medial support for the medial elbow (Park & Ahmad, 2004) against valgus force. According to Park et al. (2004) and Lin et al. (2007), the flexor carpi ulnaris is the primary active stabilizer of the medial elbow. The FPM could provide stability for the medial elbow by either the contractile component or an elastic component of the muscle tendon (Park & Ahmad, 2004). The elastic component of the FPM provides stability due to the location of the anatomy, because it directly overlaps the anterior band of the UCL (Davidson et al., 1995). The contractile components of the muscle affect elbow stability by producing force and changing the overall valgus joint angle during movement (Hsu et al., 2008). The complex anatomy of the elbow poses challenges to the clinical evaluation of the medial elbow.

The active stability of the medial elbow can be reduced by fatigue of the FPM. Fatigue of the FPM occurs commonly by overuse in throwing athletes (Wang et al., 2016). Fatigue of these muscles results in decreased force production of the muscle group. Fatigue of the forearm musculature has been shown to affect the mechanics of throwing including decreases in muscle contraction, release speed, muscle power, and ball velocity (Wang et al., 2016). Wang et al. (2016) reported no change in the elbow valgus angle following their fatigue protocol during throwing. The FPM provides active stability by creating varus moments to counteract the valgus moments created during throwing (Hsu et al., 2008). Reduction of the force production of the FPM would then lead to a decrease in medial elbow stability, because of the lack of varus moments (Hsu et al., 2008). The muscular fatigue can lead to compensation techniques and instability, both of which can lead to injury (Glousman, Barron, Jobe, Perry, & Pink, 1992; Hamilton et al., 1996). Studies have shown that fatigue is a key factor in injury during throwing motions (Wang et al., 2016; Yukutake, Kuwata, Yamada, & Aoyama, 2015). Yukutake et al. (2015) identified six factors associated with an increased risk of elbow pain in youth baseball players, four of which were related to fatigue. An association between muscular fatigue during throwing and an increased risk for injury has been established. An improved understanding of the effect of fatigue of the FPM on the assessment of medial elbow stability is thus needed.

Several authors have employed ultrasonography to explore the anatomy of the elbow and the effects of muscle fatigue on elbow function (Ciccotti et al., 2014; Sasaki et al., 2002; Wang et al., 2016). Ultrasonography is an inexpensive and point of use tool used to diagnose musculoskeletal injury in a clinical setting and can be used to image the structures of the medial elbow (Klauser et al., 2012). Specifically ultrasound (US) images can be used to measure the width of the space between the humerus and ulna (Figure 1). Ciccotti et al. (2014) states that the use of US is a less expensive alternative to magnetic resonance imaging (MRI) for imaging studies of the elbow. Ultrasound imaging can be used to test the effect of FPM fatigue on the stability of the medial elbow.

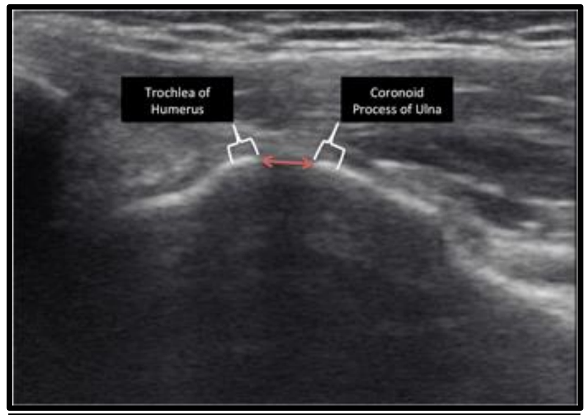

Figure 1: Depiction of the medial joint space using diagnostic ultrasound.

Purpose of the Study

Injury to the UCL can lead to reduced elbow stability. The decrease in the active stability of the medial elbow resulting from fatigue of the FPM could further increase the stress on the UCL during valgus loading seen in throwing athletes. Therefore it is important to understand the effect of fatigue of the FPM on the width of the medial joint space. The purpose of this study is to test the effect of fatigue on the FPM muscles on width of the medial joint space while under an applied valgus load.

Significance of the Study

This study will measure the width of the medial joint space during a valgus stress test before and after a bout of fatigue producing wrist flexion exercise. The flexor pronator muscle mass once fatigued, will result in a greater opening in the medial joint space with a valgus force.

The greater medial joint space opening would then subsequently put more strain on the UCL, increasing risk for injury (Fleisig et al., 1995). Increased understanding of the relationship between FPM fatigue and medial elbow stability could prevent medial elbow injuries.

Hypotheses

1. Null hypothesis: Fatigue of the FPM will not affect the width of the medial joint space. There will be no difference in the width of the medial joint space during the valgus stress test following the fatigue protocol.
2. Alternative hypothesis: The width of the medial joint space during the valgus stress tests will increase following the fatigue protocol. This increase in the width of the medial joint space will only be seen during the valgus stress tests and will not be seen without the applied valgus stress tests.

Assumptions

- All valgus forces are applied equally during pre and post fatigue protocol stress testing.
- All participants applied their greatest wrist flexion force during maximal handheld dynamometry strength testing.
- The fatigue protocol produced an appreciable level of muscle fatigue across participants.
- Participants provided maximal efforts during maximal FPM strength testing.
- All participants were honest about elbow injury history.

Limitations

- The study was performed with a general population, not on overhead throwing athletes.

- The study was performed on elbows without elbow pain, which may present differently than participants with elbow pain.
- The study used a clinical valgus stress for one of the special tests, rather than a measured device.
- The study was performed at 30^{o} elbow flexion rather than in a throwing position of around 90^{o} elbow flexion.

Delimitations

This study used healthy participants. An injured individual may react differently to various stresses and fatigue. The healthy elbows that were used with this study also did not present with innate gross elbow instability. Throwing athletes would not have the same basic elbow stability than an elbow of a non-throwing athlete due to that constant valgus stress component throughout their sport. The study was performed on participants that are not left handed throwing athletes. The study observed the FPM elbow stability changes, but it cannot be determined whether those changes are related to the elastic components of the muscle tendons during exercise or the specific changes of fatigue on those muscles. Therefore the results of this study can only be applied to a healthy non-throwing elbow.

Operational Definitions

Fatigue – Reduce in force production of the muscles measured by handheld dynamometry following repetitive exercise (Blangsted, Sjogaard, Madeleine, Olsen, & Sogaard, 2005).

Borg CR10 – Rating of perceived exertion scale used to rate exercise. Rated from 0 to 10, 0 being no effort and 10 being a maximal contraction (Borg, 1982; Pincivero, Coelho, & Campy, 2003; Robertson & Noble, 1997).

Flexor Pronator Mass (FPM) – Group of muscles which attach at the medial epicondyle of the humerus, providing active support to the medial elbow. Consists of the flexor carpi ulnaris, flexor digitorum superficialis, and the pronator teres (Lin et al., 2007; Park & Ahmad, 2004).

Quick Disability of the Arm Shoulder and Hand (QDASH) – Eleven question disability survey to quantify physical disability during everyday activity (K. G. Andersen, Christensen, Kehlet, & Bidstup, 2014).

Ulnar Collateral Ligament (UCL) – Ligament of the medial elbow originating from the medial epicondyle of the humerus and inserting on the sublime tubercle to the ulna. Provides static support to the medial elbow (Morrey & An, 1983).

Valgus Stress Test – Clinical stress applied to the elbow to stress the medial elbow. One hand of the examiner is placed on the posterolateral aspect of the ulna, while the other is placed at the distal forearm. The hand at the elbow applies a force to push the elbow medially, while the distal hand applies a lateral force to the forearm (Nazarian, McShane, Ciccotti, O'Kane, & Harwood, 2003).

Weighted Valgus Stress Test – Clinical stress applied to the elbow to stress the medial elbow using gravity. With the participant supine, place the shoulder in 90^{o} of abduction and full external rotation. Place the elbow in about 30^{o} of flexion. Attach a weight to the distal forearm and gradually lower the weight until the weight is supported by the forearm. The clinician should guide the weight to prevent changing the elbow flexion angle (Tajika et al., 2016).

CHAPTER 2

LITERATURE REVIEW

Anatomy

The flexor pronator mass (FPM) attaches on the medial epicondyle at the elbow and consists of the flexor carpi ulnaris, flexor digitorum superficialis, and the pronator teres. The general anatomy of the elbow is evidence to show that the FPM will prevent valgus forces. The FPM supports the anterior bundle because it runs just superficial (Davidson et al., 1995). The elbow is also supported in other ways. The radial head helps to reduce the valgus movement during pitching (Hotchkiss & Weiland, 1987; Morrey, Tanaka, & An, 1991). The radial head is the only bony support for the medial elbow. The soft tissue support of the UCL is the main support for the medial elbow, having the least support in a neutral position (Pomianowski et al., 2001; Safran, McGarry, Shin, Han, & Lee, 2005; Seiber, Gupta, McGarry, Safran, & Lee, 2009). Despite being the main support for preventing valgus forces, according to Fleisig et al., the torque of the elbow during the overhead throwing motion is greater than the maximal tensile load the UCL can withstand (Fleisig et al., 1995). The UCL only provides for about 55% of the forces generated when at 90^{o} of elbow flexion, with less contribution the more the elbow is extended (Morrey & An, 1983). Therefore there are other structures than the UCL working in the elbow to provide stability against active valgus forces.

Researchers have conducted studies testing the influence of the FPM on valgus and varus angles with the use of cadavers. Park et al. conducted testing on the muscle contribution to valgus elbow stability (Park & Ahmad, 2004). Researchers applied weight to the specific muscles of the elbow to simulate their contraction individually as well as selected pairs in cadaver elbows with cut UCL's at 30^{o} and 90^{o} elbow flexion; they reported the flexor carpi ulnaris produced the greatest significant valgus joint decrease in degrees, followed by the flexor digitorum superficialis, with the pronator teres providing no significant change (Park & Ahmad, 2004). Lin et al. (2007) performed a similar study at 45^{o} and 90^{o}, with similar significant changes across all contributions. Researchers reported the FPM contraction produces a a varus moment, helping to provide relief for the UCL, the greatest contribution being provided by the flexor carpi ulnaris (Lin et al., 2007). Another study reported that loading the FPM muscles produced a significant decrease in valgus joint angle (Udall, Fitzpatrick, McGarry, Leba, & Lee, 2009). The researchers tested each muscle under the varied conditions based on elbow flexion (30^{o}, 60^{o}, and 90^{o}), ligament status (intact, stretched, and torn), and forces applied to each muscle (forearm weight, forearm weight +.75Nm, and forearm weight +1.5Nm). Their results indicated the FPM reduces the valgus angle significantly, while the flexor digitorum superficialis produced the greatest angle changes individually (Udall et al., 2009). These studies all suggest that the contraction of the FPM provides stability to the medial elbow.

Testing has been conducted to measure valgus angle during the muscle activations in vivo in a lab setting. Researchers have measured the individual muscles contributions to flexion, extension, supination, pronation, valgus, and varus movements (Hsu et al., 2008). Hsu et al. (2008) suggested the flexor carpi ulnaris to be the main contributor to varus movements, with significant changes at 0^{o}, 30^{o}, 60^{o}, and 90^{o}. The flexor carpi radialis and pronator teres however only suggested significant changes at the 90^{o} mark, with increasing significance the closer to the 90^{o} (Hsu et al., 2008). The study provided evidence to support the concept that the position of the muscles provides dynamic stability for the medial elbow.

Biomechanics

Early studies viewed the electromyograph contributions of the FPM during throwing motions (Glousman et al., 1992; Hamilton et al., 1996; Werner, Fleisig, Dillman, & Andrews, 1993). Research done by both Glousman et al. and Hamilton et al. suggests that a decrease in FPM firing as well as an increase in extensor supinator mass firing may be leading to elbow injuries in pitchers (Glousman et al., 1992; Hamilton et al., 1996). Some differences in muscle activation were reported between pitchers with and without elbow injuries (Hamilton et al., 1996). It was reported that during the acceleration and deceleration phase, the injured players were not activating the flexor carpi radialis as much as the non injured players (72% vs. 115% baseline during acceleration; 50% vs. 79% baseline during deceleration). The flexor carpi ulnaris activity was significantly different during early cocking (9% vs. 25%), deceleration (44% vs. 77%), and follow through (11% vs 24%) (Hamilton et al., 1996). Hamilton et al. (1996) reported no significant muscle activation difference between groups with the flexor digitorum superficialis or the pronator teres. Many studies have reported that the FPM has significant firing to reduce valgus forces at the elbow and reduce the valgus angle during throwing.

Counter-arguments

The study conducted by Ciccotti et al. measured joint spacing using US on cadavers (Ciccotti et al., 2014). The researchers proceeded to cut individual structures while applying a valgus stress to the elbows. They cut soft tissue structures of 12 elbows with two different sequences: transverse bundle of the UCL, posterior bundle of the UCL, anterior band of the anterior band of the UCL, posterior band of the anterior UCL and the FPM; the second sequence was in reverse order (Ciccotti et al., 2014). Their data suggested significant changes for cutting the FPM only during the first sequence when it was the last structure cut, but not when it was the first (Ciccotti et al., 2014). In a study by Osbahr et al. (2010), elbow injuries were observed in a diverse age of throwers. Researchers reported that majority of injuries that included the FPM as well as the UCL occurred in the population above the age of 30, with 88% predictability that FPM involvement meant the athlete was older than 30 (Osbahr et al., 2010). The predictability for FPM involvement could indicate that the relationship between the FPM and the UCL is not as relevant for the application aspects of a typical athletic population. The UCL is supported by the FPM actively, but this study methods are done through static positions.

Fatigue

Fatigue of muscles leads to a decrease in the amount of force the muscle can produce (Blangsted et al., 2005). Force production of a muscle is reduced after fatigue (L. L. Andersen et al., 2010; Blangsted et al., 2005; Cowley & Gates, 2017; Mullaney, McHugh, Donofrio, & Nicholas, 2005; Wang et al., 2016). Fatigue is used vaguely throughout research, meaning either gradual declines in force production or the endpoint of a sustainable activity (Enoka & Duchateau, 2008). With many varying definitions, the use of measurable force production as well as perceived effort can adequately assess fatigue (Enoka & Duchateau, 2008). Cowley & Gates (2017) performed a study based on fatigue of either grip strength or shoulder strength. For either protocol, they reported that both during and after the fatigue protocol, the maximal voluntary contraction forces were significantly reduced (Cowley & Gates, 2017). Therefore within the current study fatigue will be defined and assessed as a reduction in force production.

Fatigue of muscles occurs due to multiple factors of physiological, physical, and neural changes during exercise tasks (Enoka & Duchateau, 2008; Lorist, Kernell, Meijman, & Zijdewind, 2002). Muscle spindles help to realize the muscle length and maintain the proper amount of signal sent to produce a contraction (Brooks, Allen, & Proske, 2013). To maintain a contraction the muscle fibers may be producing the same force, but the force is maintained by increasing the number of neurons firing to activate the muscle motor units (Lorist et al., 2002). Despite the force production not changing, the effort of the participant increases due to the increased neuromuscular involvement in order to maintain that contraction (Lorist et al., 2002). Fatigue can be measured by reduction in force, changes within electromyographic activity or an exhaustion of motor function (Enoka & Duchateau, 2008). Due to the increased motor neuron activity, an increase in electromyographic activity while maintaining the same or decreased force production is often used to measure fatigue (Enoka & Duchateau, 2008). Metabolic factors effect fatigue due to the necessary rate for the action potential polarization and depolarization as well as the energy systems used and adenosine triphosphate available for use (Enoka & Duchateau, 2008). Fatigue can be characterized by differences in neural activity, metabolic rates, and decreases in force production; due to simplicity many researchers simply identify fatigue by a reduction in measurable force production (Enoka & Duchateau, 2008).

Fatigue has been quantified in many other studies before. Due to the intended application of the current study for further research with throwing athletes, the desirable amount of fatigue should be close to what would be expected during throwing sports. Wrist flexion strength isn't usually the target of baseball fatigue studies, but shoulder strength is often investigated. One study had 13 baseball pitchers test their shoulder strengths before and after competition for 19 games (Mullaney et al., 2005). Their study reported that shoulder flexion had a force reduction of 15% ($p = 0.02$), shoulder internal rotation had a force reduction of 18% ($p = 0.03$), and shoulder adduction had a force reduction of 11% ($p = 0.01$) (Mullaney et al., 2005). Therefore the participants' shoulders fatigued around 10-20% after pitching in a competitive environment.

For the current study the desirable amount of fatigue will be 15% to have close to competition force reductions.

A study was performed measuring the joint angles and muscle force production in pitchers before and after a fatigue protocol (Wang et al., 2016). The researchers had performed the study with 15 pitchers, age 19±2.1 years of age, that had been pitching for at least five years (Wang et al., 2016). The participants were tested for throwing biomechanics using an eight camera motion analysis sytem and an electromyography system along the flexor carpi ulnaris, flexor carpi radialis, and extensor carpi radialis of the dominant arm (Wang et al., 2016). After a warm up of 15 minutes, the participants were recorded for six maximal effort fastballs (Wang et al., 2016). After recording these measures, the participants completed a fatigue protocol of wrist unlar deviation and flexion, which consisted of three sets of 8-12 repition max at a set metronome pace of 20 beats per minute (Wang et al., 2016). After fatigue was observed using their protocol, the participants pitched six fastballs to observe any differences in force production or pitching mechanics (Wang et al., 2016).

The Wang et al. (2016) results suggested that the strike percentage was significantly lower post-fatigue (70.11±17.79% pre-fatigue to 49.33±17.24% post-fatigue), but the ball speed and joint angle velocities did not decrease as they expected. They concluded that this occurred due to muscle compensation. The muscle activity from the flexor carpi radialis was insignificantly decreased and the flexor carpi ulnaris was actually significantly higher after the fatigue protocol; while the increase still maintained the pitch speed, it was not compensating enough to maintain pitch accuracy (Wang et al., 2016). This increase in muscle activity also provides support to the UCL by providing a necessary decrease in varus tension (Wang et al., 2016). Researchers stated that further fatigue would possibly lead to greater changes in the throwing mechanics (Wang et al., 2016). Therefore fatigue can have significant impacts on the FPM muscle firing.

Medial elbow injury can be caused by a valgus torque to the forearm, which needs to be counter acted on by a varus torque (Fleisig et al., 1995). A study by Hsu et al. (2008) as described previously, identified the importance of the FPM muscles providing medial elbow stability by creating varus movements and relieving loads on the UCL. They concluded that the FPM is important to strengthen and rehabilitate in order to prevent failure of the UCL (Hsu et al., 2008).

Muscle Elasticity

Tendons provide a strong tensile strength connective tissue to connect the belly of muscles to bones for force production (Joseph et al., 2014). A study performed by Joseph et al. (2014), was conducted to test exercise effects on the achilles tendon's biomechanics within 31 participants (17 male, 14 female). They assessed the participants' maximal voluntary contraction as well as the tendon stiffness at baseline, after a 10-minute walk, and after performing 100 "toe jumps" (jumping with a straightened knee) on a Smith machine set up with 20% of the participants' body weight (Joseph et al., 2014). No statistically significant changes in the males' tendon stiffness were reported. However, the researchers reported a statisticaly significant reduction in tendom stiffness of females (536.2 ± 120.0 N/mm to 369.7 ± 91.7 N/mm; $p < 0.001$) following the "toe jumping" fatigue protocol (Joseph et al., 2014). Tendon tensile length is controlled through muscle spindles to facilitate contractions and prevent injury (Brooks et al., 2013). When fatigued these muscle spindles do not contract at as carefully measured strengths as normal, leading to over and under compensations in force (Brooks et al., 2013). Therefore the participants within the current study may have increased stretch within the tendon based on gender differences and lack of musclular control.

Perceived Exertion

The Borg scale is a subjective reported scale of perceived effort given by the participant after any given task (Borg, 1982). Perceived exertion can quantify physical strain by integrating multiple nervous system signals of the participant from the peripheral muscles and joints, central cardiovascular and respiratory systems, and the central nervous system (Borg, 1982). The participant's body will have a stimulus response to exercise which can affect physiological mediators, psychological factors, performance factors, and exertional symptoms (Robertson & Noble, 1997). All of these stimuli are transmitted throughout the sensory cortex as a perceptual reference of work, which leads to the particpant's response within these systems (raised heart rate, sweating, heavier breathing, etc.) as well as overall psychological response (anxiety, depression, exercise experience, etc.) (Robertson & Noble, 1997). The particpant's overall perceived efforts can be measured through the use of the Borg scaling using different scalings and reference numbers (Robertson & Noble, 1997). The Borg CR-10 scale was chosen for the ratio scale to quantify the perceived efforts to the amount of force necessary for the muscle contraction during the exercises.

The Borg CR-10 scale is commonly referenced and rated with participants knowing verbally the wording very heavy, heavy, moderate, light, very light, and the difference between them (Borg, 1982). The scaling used within the current study was CR-10, but was verbally given in a later established method (Pincivero et al., 2003). The verbal queues given to the participant followed a maximal voluntary contraction and were stated as "Think about the feelings within your forearm during the contraction, and think of that feeling as a maximal contraction" to establish the maximal effort of ten (Pincivero et al., 2003). The lower limit of zero is verbally referenced as performing no work, with the muscle at rest (Pincivero et al., 2003). The use of the CR-10 scale for perceived exertion can be effective at measuring the percentage of a one repetition maximum (Pincivero et al., 2003). The goal with the scaling would be for a 50% contraction of the one repetition maximum would coorelate to a five on the scale, but the lower ranges of the scale are less consistent (Pincivero et al., 2003). The perceived effort matched well when in the 70-90% repetition maximum range, but was generally underestimated within the 10-60% range (Pincivero et al., 2003). The Borg CR-10 scale can be effective in comparing work within participants, which will benefit this study by measuring changes in perceived exertion over the course of the three sets of the fatigue protocol.

The Borg CR-10 scale can be used as an outcome to verify participant fatigue (Cowley & Gates, 2017). Cowley & Gates (2017) studied how proximal and distal fatigue protocols can affect coordination of basic tasks. They had fourteen participants perform repetitive rachet tasks before and after a fatigue protocol of either grip strength of shoulder flexion (Cowley & Gates, 2017). Measurements for maximal voluntary contractions were also conducted for shoulder flexion and grip strength with RPE's recorded (Cowley & Gates, 2017). During the fatigue protocol and post-fatigue they reported a significant decrease in maximal voluntary contractions of shoulder strength during the proximal fatigue protocol and a significant decrease in maximal voluntary contractions of grip strength with the distal fatigue protocol (Cowley & Gates, 2017). The RPE increased significantly regardless of protocol due to the muscular fatigue (Cowley & Gates, 2017). Therefore ratings of perceived exertion can be utilized to verify fatigue.

Ratings of perceived exertion work mainly within participants and can be hard to quantify between participants. Pincivero et al. (2003) reported that gender differences are not statistically significant. The reported patterns in percentage of one repetition maximum were consistent regardless of gender within the study, due to the perceived exertion scale disregarding body mass and force production (Pincivero et al., 2003). Despite the male (81.50 ± 13.67 kg) participants lifting significantly heavier one repetition maximums compared to the females (48.99 ± 9.84 kg), perceived exertion was still accurate (Pincivero et al., 2003). Perceived exertion being unaffected by gender is beneficial because of the inclusion of male and female participants within the current study.

A study testing the differences between elastic Therabands™ and dumbbell weights for exercise was conducted with the use of EMG and the Borg CR-10 scale as outcome measures (L. L. Andersen et al., 2010). They coorelated the weighted of applied resistance between the Therabands™ and dumbbells and had participants perform exercises to ensure their numbers were accurate (L. L. Andersen et al., 2010). The loading between both groups reported no statistically significant differences between measures of difficulty with both EMG and the Borg Scale (L. L. Andersen et al., 2010). The measures of the Borg scale within their study while using the blue Theraband™ was 3.8 ± 0.4 (L. L. Andersen et al., 2010). With no stastitical difference between Theraband™ and dumbells, the use of Theraband™ is a valid resistance method.

Special Tests

The first special test used for this study is the clinical valgus stress test. The clinical valgus stress test is performed by placing one hand on the lateral epicondyle of the humerus, which acts as the fulcrum point for the stress (Eygendaal, Heijboer, Obermann, & Rozing, 2000). The opposite hand is on the distal portion of the participant's forearm, applying a lateral force to the forearm (Eygendaal et al., 2000). The clinical valgus stress test can be used during ultrasound to assess the width of the medial joint space of the elbow (Nazarian et al., 2003). Their study was conducted by measuring 26 asymptomatic Major League Baseball pitchers (Nazarian et al., 2003). They measured the medial elbow at 30^o of flexion during their valgus stress test (Nazarian et al., 2003). The clinician applying the valgus stress test was the head athletic trainer for their baseball team for 15 years (Nazarian et al., 2003). They suggested that the clinical valgus stress test is a good tool to be used to measure the width of the medial joint space, but were also limited by the fact that the force can be varied on each application of the stress (Nazarian et al., 2003). They addressed the limitation by having the same athletic trainer apply the stress throughout the evaluations (Nazarian et al., 2003). Therefore the use of a clinical valgus stress can be used to evaluate the width of the medial joint space, as this study will utilize a similar design and have the clinician applying the valgus stress.

The second special test used will be the weighted valgus stress test. This test will be performed by having the participant lying supine on the edge of the table, with the shoulder at 90^o of abduction, full external rotation, and 30^o of elbow flexion (Bica, Armen, Kulas, Youngs, & Womack, 2015). Their study design involved comparing the reliability of a gravity dependent condition and the weighted valgus stress test, with a five pound weight, using ultrasound to assess medial joint space (Bica et al., 2015). Their study reported good to near perfect ICC's for ulnohumeral joint gapping, ICC = 0.75-0.94 with a 95% confidence interval, with a standard error of measurement of 0.3-0.4 (Bica et al., 2015). Applying a standardized stress to the elbow joint is also much more reliable than a clinical valgus stress test (Bica et al., 2015). Therefore this test can be a reliable tool for this study to measure the joint space of the medial elbow.

Ultrasound

Ultrasonography will be used to image the stability of the elbow. The use of US is a cost effective alternative that has been reported as being acurate in observing the structures of the medial elbow (Kane et al., 2014). However results are more operator dependent (Kane et al., 2014). A systematic review observed the UCL as the second highest grading on their scale for imaging, indicating US as equivalent to other imaging techniques (Klauser et al., 2012). Stress testing can easily be done during US examination to test the UCL's condition (De Maeseneer et al., 2015; Tagliafico et al., 2015). The technique of cradling the medial epicondyle from the proximal end between 2^{nd} to 4^{th} fingers will align the US head directly over the UCL and FPM (De Maeseneer et al., 2015). The use of US in stressed conditions to measure joint opening has shown great success with the use of a Telos GA-II E Stress Device (TSD) (Austin & Associates Fallston, MD) (Smith, Hackel, Goitz, Bouffard, & Nelson, 2011). Given the superficial aspects of the medial elbow, the use of US is a valid method to measure and stress the UCL and FPM (Farrow, Mahoney, Sheppard, Schickendantz, & Taljanovic, 2014).

Conclusion

Fatigue of skeletal muscles has been shown to reduce the amount of force that the muscle can produce. The stability of the medial elbow is provided by the UCL and the FPM. The effects of fatigue of the FPM on the stability of the medial elbow has not been fully explored. The stability of the medial elbow can be assessed by measuring the width of the medial joint space during valgus loading. The current study observed the effects of fatigue of the FPM on the width of the medial joint space during valgus stresses.

CHAPTER 3
METHODS

Purpose

The purpose of this study was to evaluate the effect of fatigue of the FPM muscles on the width of the medial joint space of the elbow while under an applied valgus load.

Participants

The study was conducted with 31 participants (18 female and 12 male, 1 excluded due to previous injury). Demographic data has been recorded and is presented in Table 1 below. Range of motion, QDASH scores, and end-feels were recorded to ensure that the participant had within average normal limits. Researchers measured and tested the left arm of the participants. A pilot study was performed on 7 participants in order to perform sample size calculations. The 95% confidence interval for the minimal detectable change for the width of the medial joint space based on the pilot test retest data was in the 0.36mm. The sample size calculations were performed using G*Power version 3.0.10 (University Kiel, Germany copyright 1992-2008). Statistical power was set at $1-\beta = 0.80$, statistical significance was set at $p < 0.05$, in order to detect difference of 0.36mm a sample size of 15 participants are required. The additional participants were tested in order to assure statistical power for interaction effects and any post posteriori analysis.

Inclusion Criteria

- Participants between 18 and 30 years old.
- Participants with healthy left elbows.

Exclusion Criteria

- Left handed overhead throwing athlete at the high school level or higher.
- Participants younger than 18 years old or older than 30 years old.
- Participants with previous elbow or shoulder injuries to their left side.
- Participants that cannot sit still for at least five minute periods.
- Participants that fail to complete the fatigue protocol, due to pain or any other reason.

Demographic Data		
Outcome Measure	Mean ± SD	
Subjects	31	
Included	30	
Excluded	1	
Age (years)	21.5 ± 1.9	
Sex (M / F)	(12 / 18)	
Height (cm)	170.2 ± 10.1	
Weight (kg)	71.2 ± 15.6	
QDASH	0.8 ± 2.3	Normal ROM
Elbow Flexion	138.9 ± 4.9°	140°-150°
Elbow Extension	6.6 ± 4.5°	0°
Pronation	88.3 ± 4.6°	80°
Supination	89.8 ± 6.7°	80°
Wrist Flexion	69.6 ± 12.2°	60°
Wrist Extension	58.7 ± 10.0°	60°
External Rotation	100.0 ± 11.0°	90°
Internal Rotation	75.5 ± 11.6°	70°
Abduction	178.8 ± 2.9°	180°
Shoulder Flexion	178.2 ± 3.7°	180°
Valgus Positive Tests	0	
Valgus Negative Tests	30	
Valgus Firm End-feel	30	
Valgus Empty End-Feel	0	

Table 1 Participant Demographics: Includes all demographic data recorded for the participants.

Equipment

- Standard athletic training table
- Mindray M5 ultrasound unit
- Standard ultrasound gel
- Customized handmade arm support

- Baseline™ plastic goniometer
- Baseline™ digital inclinometer
- Standard five pound ankle weight
- Blue TheraBand™
- microFET2™ handheld dynamometer
- Baseline™ hydraulic grip strength dynamometer

IRB Approval

The participants were informed of the procedure steps and signed a written consent form prior to the start of testing procedures. This investigation has been approved by the Marshall University Institutional Review Board (IRBNet ID #868319-2). A copy of IRB approval can be found within appendix A. Informed consent forms can be found within appendix B.

Design

Paired t-tests were done in order to assess fatigue by reduction in force production. A two way repeated measures design, stress by fatigue was used to assess the effect of flexor muscle fatigue on medial elbow stability during valgus loading. The width of the medial joint space of the elbow was measured on ultrasound images collected under two conditions of valgus stress application before and after a FPM fatigue protocol.

Protocol

Ultrasound images were taken of the width of the medial joint space during valgus stress tests, in the unstressed and stressed positions. Ultrasound imaging was completed prior to and immediately after the fatigue protocol. Participant demographics were collected for age, height, weight, Quick Disability of the Arm Shoulder and Hand (QDASH), and active range of motion (elbow flexion, elbow extension, wrist flexion, wrist extension, pronation, supination, shoulder external rotation, and shoulder internal rotation). The QDASH can be found within appendix C. The data collection sheets can be found within appendix D. Descriptions of the range of motion measurement procedures can be found within appendix E. Measurements of the participant’s wrist flexion, wrist extension, and grip strength were taken before and after the fatigue protocol. Three repetitions of each strength test were performed, the mean of the three repetitions was used for analysis. The participants then completed a fatigue protocol for wrist flexion using a blue TheraBand™. The fatigue protocol consisted of three sets of 30 wrist flexion repetitions in a slightly flexed position (about 10^{o}). The amount of fatigue was quantified by measuring a decrease in their wrist flexion strength. Wrist flexion strength were taken in between bouts of the wrist flexion exercise during the fatigue protocol. Borg CR-10 ratings of perceived exertion was used to subjectively quantify fatigue.

Three clinicians were used for the imaging process (Figure 2). One clinician saved the ultrasound images. The second clinician applied the various stress tests. The third clinician obtained the ultrasound image with the ultrasound head.

Figure 2: Clinician set-up during data collection.

Procedures

Participant Positioning. The participants were positioned supine on a standard athletic training table (Figure 2). The participants were shifted all the way to the left side of the table so that the left shoulder was on the edge of the table (Figure 2). During testing the participants had their arm supported by a device made for this study from PVC piping and wood (Figure 3). Blue TheraBand™ was attached to the base of the support with a handle for the fatigue protocol (Figure 3).

Figure 3: Custom handmade arm support.

Ultrasound. The test was performed using an ultrasonography machine, the Mindray M5. The Mindray M5 ultrasound unit has a measurement error of ±3^{o} when measuring a distance in millimeters. The transducer used was a linear transducer. The medium was a generic US gel.

Ultrasound images were taken of the left width of the medial joint space. These images were taken with the participant supine on a standard athletic training table. The humeroulnar joint space was imaged on the medial aspect of the elbow just distal to the medial epicondyle. The joint space was identified using a method described by De Maeseneer et al. (2015); using the second to fourth fingers, clinicians cradle the medial epicondyle from an anterior and superior angle, with fingers pointed distally (De Maeseneer et al., 2015). The US head was held from that point longitudinally along the medial elbow over the UCL (De Maeseneer et al., 2015).

The ultrasound images were taken during the valgus stress tests during the unstressed and stressed conditions. The participants left arms were placed into a customary handmade arm support device; the device held the arm in 90^{o} of shoulder abduction, and maximal glenohumeral external rotation. An investigator held the participant's forearm in supination and the elbow at 30^{o} of elbow flexion during all imaging. According to research, the FPM has the greatest contribution to medial elbow stability in a 30° flexed position (Lin et al., 2007; Park & Ahmad, 2004). An examiner supported the wrist to prevent gravity stresses. The unstressed and valgus stress test images were collected while in this standard position.

Ultrasound images were taken two times in each condition. Two different valgus stress tests had been utilized: a clinical valgus stress test and a weighted valgus stress test. The ICC values for the unstressed position ranged from 0.864- 0.983, and for the stressed condition ranged 0.939- 0.961. The average SEM was 0.119 mm for the unstressed position, and was 0.127 mm for the stressed position. The average MDC for the unstressed position was 0.169 mm, and for the stressed position 0.179 mm. The mean measurement of the medial joint space was 2.58 mm in the unstressed position and 3.24 mm for the stressed position, leaving an average difference of 0.661 mm. ICC measurements were also conducted for reliability of ultrasound measures, which came out good (ICC of 0.890). Measurement accuracy of the width of the medial joint space was in the following order: unstressed (ICC of 0.876), weighted stress test (ICC of 0.812), and valgus stress test (ICC of 0.735).

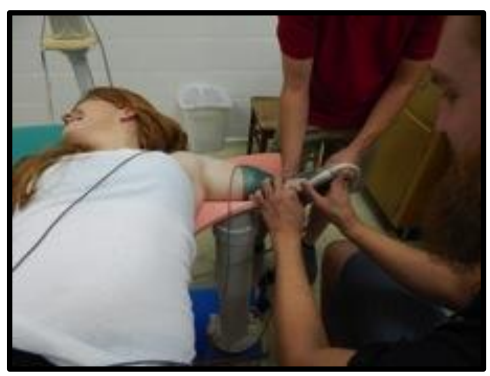

Figure 4: The clinical valgus stress test.

Valgus Stress Test. The clinical valgus stress test was performed by placing one hand on the lateral epicondyle of the humerus, which acts as the fulcrum point (Kane et al., 2014). The opposite hand was on the distal portion of the participant's forearm, pushing the forearm laterally (Kane et al., 2014). Supine modified positioning of the clinical valgus stress test can be seen in Figure 4. The weighted valgus stress test was performed by having the participant take a five-pound ankle weight attached distally around their wrist and allowing the stresses of gravity and the weight to apply a valgus force. During this test, the investigator held the elbow in the 30° of flexion. Pilot testing has been conducted for accuracy of measurements.

Strength Measures. A handheld dynamometer was used to measure the participant's wrist flexion, extension, and grip strength (Figure 5). The technique used to gather the strength measures was a standard make test, which involves no joint movement from the participant and no movement of the dynamometer or tester (Bohannon, 1988). The make test involved matching the force of the participant in order to obtain an accurate measure (Bohannon, 1988). The participant's left arm was stabilized by the arm support as well as one hand of the investigator, which was at the distal forearm (Figure 5). The researcher placed the dynamometer at the distal end of the metacarpals in order to ensure accurate wrist flexion and extension measurements (Figure 5). The wrist flexion and extension measurements were taken three times each. Three trials were performed to make the participant familiar with the specific motions and contractions. A handheld grip dynamometer was used to measure the participant's grip strength. The handheld grip dynamometer was used for two measures at both the 2nd and 3rd

Figure 5: (Left) Dynamometer equipment used. (Right) Test position for wrist flexion dynamometry.

notches, totaling four grip strength measures. All of these measures were taken before and after the fatigue protocol.

Fatigue Protocol. After baseline strength measures were completed, the participant began the fatigue protocol. The researcher handed the participant a handle attached to a blue TheraBand™, which extended to the base of the arm support to provide the tension (Figure 6). The participant was instructed to do slow and controlled repetitions from a neutral wrist flexion angle to maximal wrist flexion, while the examiner stabilized the wrist distally to help isolation (Figure 6). The exercise was performed at a self-selected pace, not controlled by a metronome. The fatigue protocol consisted of three sets of 30 wrist flexion repetitions. In between each set of 30 repetitions, the wrist flexion strength was measured twice using the handheld dynamometer. Pain and perceived exertion using Borgs CR-10 scale was also assessed between sets. Pain was measured using a standard eleven-point visual analogue scale measuring from zero to ten (Borg, 1982). Exertion was measured using a Borg CR-10 scale after each set (Borg, 1982). The participant's maximal and minimal contraction perceptions were determined during the maximal strength measures procedure. The Borg CR-10 scale limits were set by having the participant rate their perceived exertion compared to their previous maximal voluntary contraction as a ten on the scale, which was measured during dynamometry strength testing. The strength averages were quantified and compared from before the protocol to after

Figure 6: Wrist stabilization and fixation of TheraBand™ during the fatigue protocol.

the protocol. Feasibility of the fatigue protocol was performed in pilot testing. Pilot testing results suggested that the fatigue protocol induced a desirable amount of fatigue of the FPM of greater than 15%. During pilot testing the fatigue protocol produced a mean decrease in wrist flexion strength of 19.6%, ($P = 0.002$).

Data Analysis

Descriptive means and standard deviations were reported for all demographic variables. All participant and clinician generated data were recorded on paper documents and then entered into an electronic data for analysis. Force production measures were entered into a paired t-test to establish differences. Ultrasound measurements of the width of the medial joint space of the elbow were entered into the three-way repeated measures ANOVA (stress (2) x fatigue (2) x test (2)). All statistical analysis was performed with SPSS 22.0 (SPSS, Chicago, IL). Statistical significance was determined a priori at $p < 0.05$.

CHAPTER 4

RESULTS

Fatigue State

Strength measures. The wrist flexion strength measured by handheld dynamometer decreased from an average of 22.6 ± 7.7 to 20.9 ± 8.3 lbs. after three sets of the fatigue protocol (Figure 7). Wrist flexion strength decreased following the fatigue protocol, mean decrease = 1.6 ± 2.3 lbs. ($t = 3.840$; $p = 0.001$; 95% Confidence interval 0.8 to 2.5 lbs.). The fatigue protocol produced a mean decrease to 92.5% of the participants' pre-fatigue protocol maximum wrist flexion strength. The decrease in wrist extension strength was not statistically significant measuring an average of 21.0 ± 8.3 lbs. pre-fatigue to 21.3 ± 8.7 lbs. ($t = -1.012$; $p = 0.32$) after the fatigue protocol (Figure 7). Grip strength decreased following the fatigue protocol (Figure 8). The grip strength at the 2nd notch decreased from 88.0 ± 27.4 to 83.2 ± 25.4 lbs. ($t = -3.731$; $p = 0.001$). The mean decrease at the 2nd notch was 4.8 ± 6.9 lbs. The grip strength at the 3rd notch decreased from 77.3 ± 27.4 to 75.3 ± 25.8 lbs. ($t = -2.429$; $p = 0.022$). The mean decrease at the 3rd notch was 2.1 ± 4.6 lbs. Borg CR-10 scale was used between and after each set of wrist flexion exercises (Figure 9). The participants' perception of effort increased from the first set (2.1 ± 1.9) to the third set of exercises (2.7 ± 2.2, $t = 1.928$; $p = 0.06$), but this increase was not statistically significant ($t = 1.928$; $p = 0.064$).

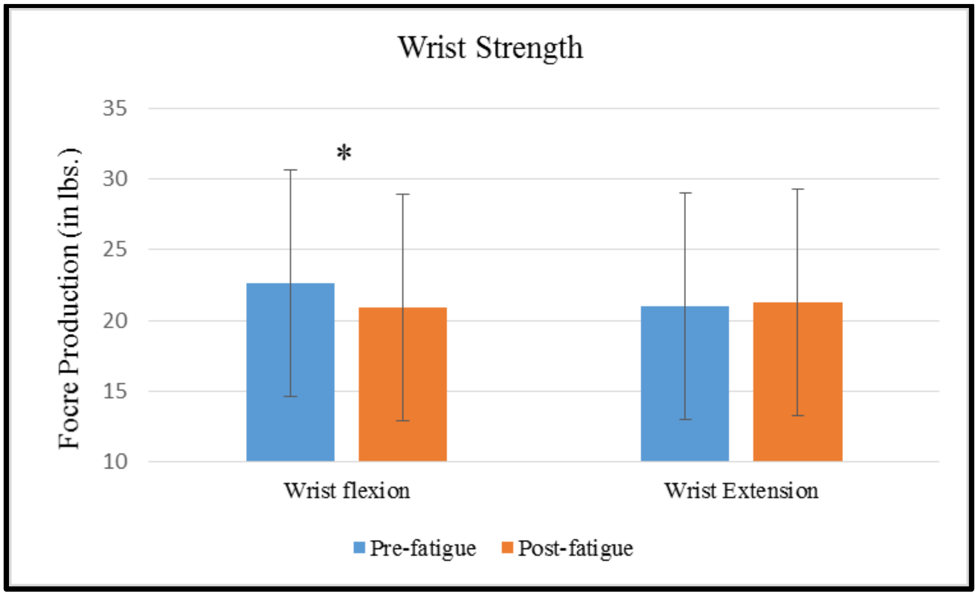

Figure 7: Wrist Strength. Measured by handheld dynamometer in pounds pre-fatigue and post-fatigue. Error bars represent standard deviation. * $p < 0.05$.

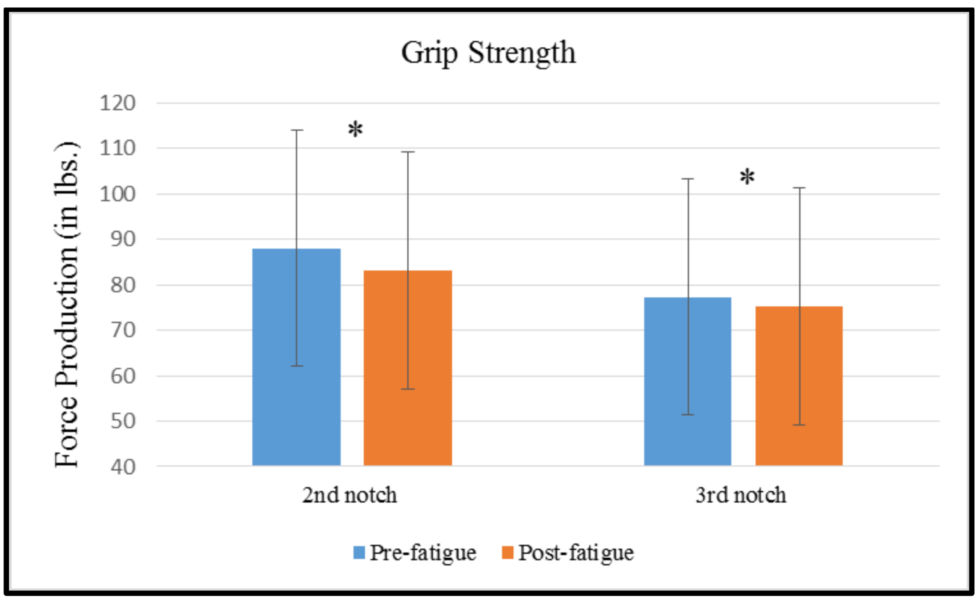

Figure 8: Grip Strength. Measured by handheld dynamometer in pounds pre-fatigue and post-fatigue. Error bars represent standard deviation. * $p < 0.05$.

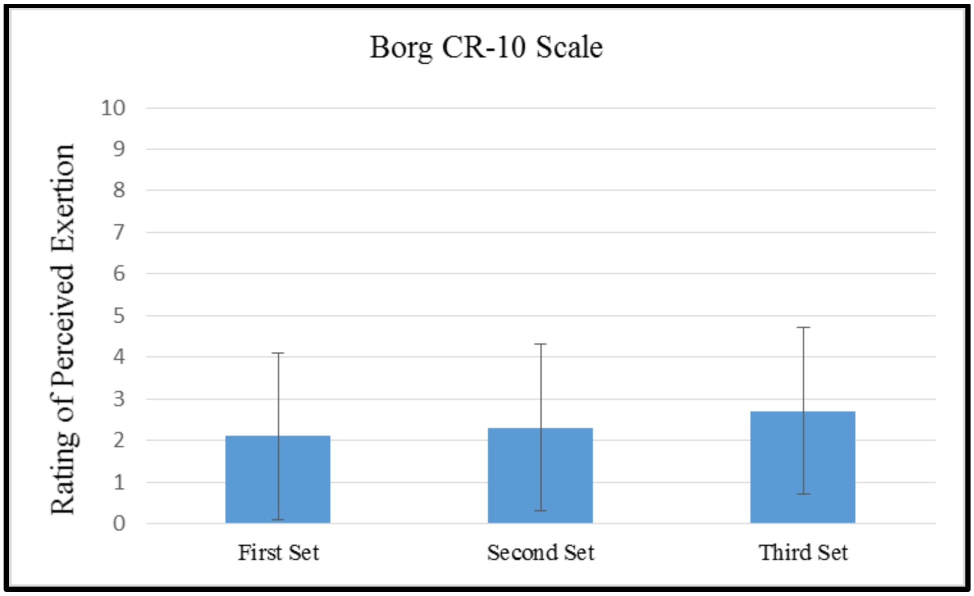

Figure 9: Borg CR-10 Scale. Reported ratings of perceived exertion after each set of thirty wrist flexion repetitions. Error bars represent standard deviation.

Width of the Medial Joint Space

Stress Main Effect. The width of the medial joint space increased with an applied valgus stress (Figure 10). The stressed main effect was found statistically significant at ($F_{(29,1)}$ = 403.9, $p < 0.001$), with an observed power of 1.00. The mean width of the medial joint space in the unstressed condition was 2.8 ± 0.1 mm (95% CI of 2.6 mm to 3.0 mm) (Figure 10). The mean width of the medial joint space in the stressed condition was 3.6 ± 0.1 mm (95% CI of 3.4 mm to 3.8 mm).

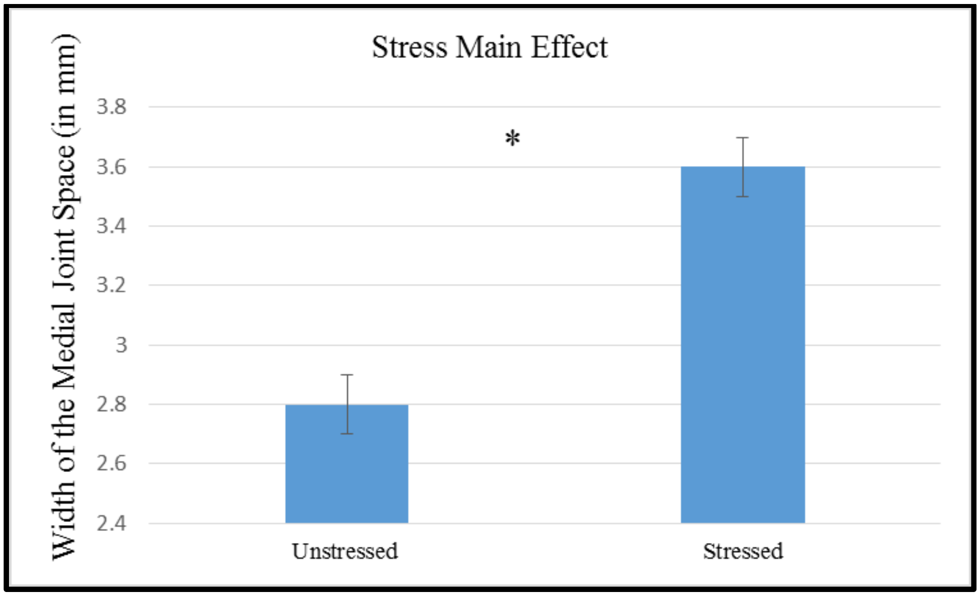

Figure 10: Stress Main Effect. The width of the medial joint space in millimeters in unstressed and valgus stressed conditions, collapsed across test and fatigue. Error bars represent standard error. * $p < 0.05$.

Fatigue Main Effect. The width of the medial joint space increased following the fatigue protocol (Figure 11). The fatigue main effect was statistically significant ($F_{(29,1)} = 7.4$, $p = 0.011$), with an observed power of 0.746. The mean width of the medial joint space pre-fatigue was 3.2 ± 0.1 mm (95% CI of 2.9 mm to 3.4 mm). The mean width of the medial joint space post-fatigue was 3.2 ± 0.1 mm (95% CI of 3.0 mm to 3.4 mm).

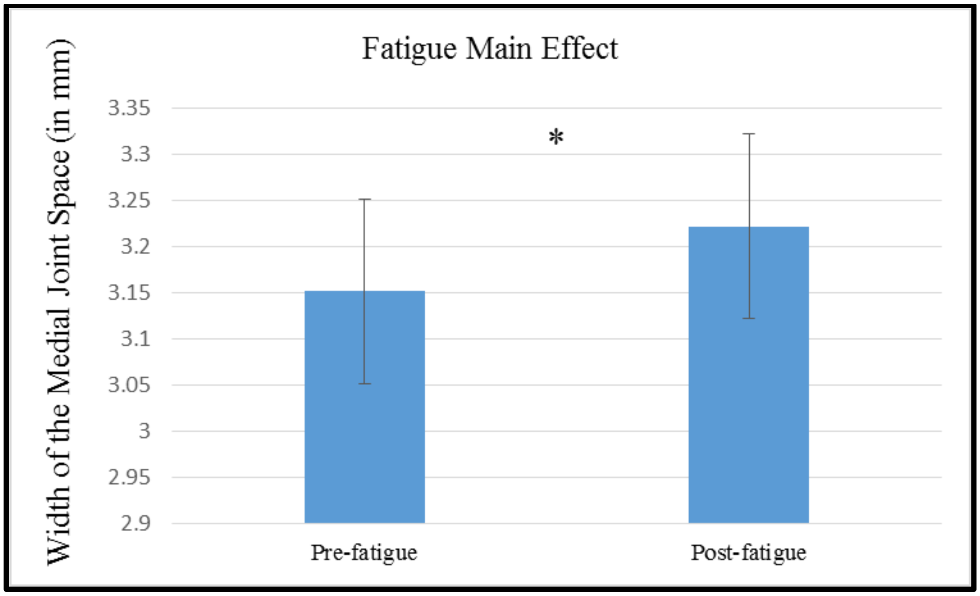

Figure 11: Fatigue Main Effect. The width of the medial joint space in millimeters pre-fatigue and post-fatigue collapsed across test and stress. Error bars represent standard error. * $p < 0.05$.

Tests Main Effect. There was not a statistically significant difference in the width of the medial joint space ($F_{(29,1)} = 3.5$, $p = 0.073$) between the clinical valgus stress test and weighted valgus stress test (Figure 12). The mean width of the medial joint space during the clinical valgus stress test was 3.2 ± 0.1 mm (95% CI of 3.0 mm to 3.4 mm). The mean width of the medial joint space during the weighted valgus stress test was 3.2 ± 0.1 mm (95% CI of 3.0 mm to 3.4 mm).

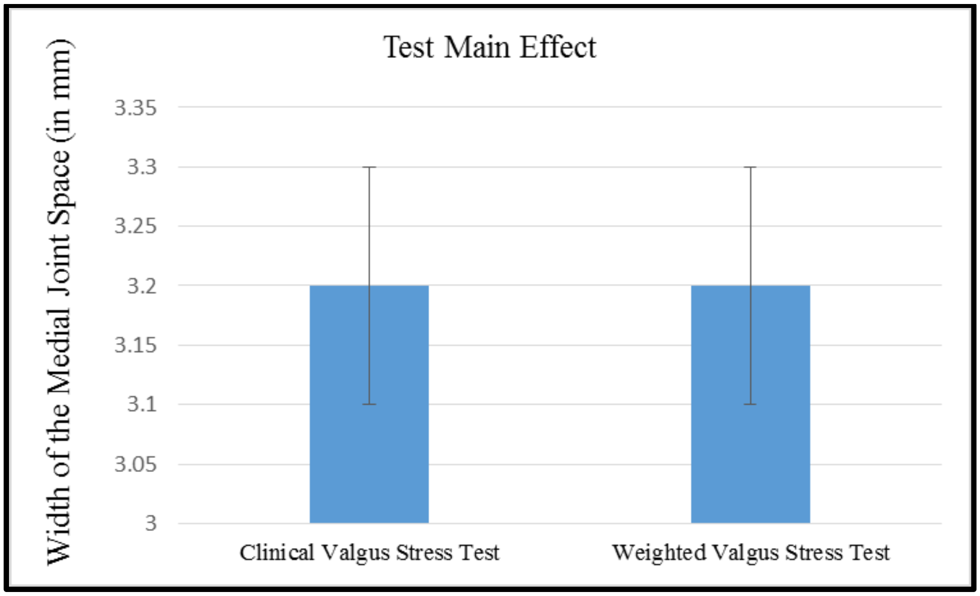

Figure 12: Test Main Effect. Width of the medial joint space in millimeters during clinical and weighted valgus stress tests, collapsed across stress and fatigue. Error bars represent standard error.

Interaction Effects

Stress * Fatigue Interaction. The increase in the width of the medial joint space with applied valgus stress was greater post-fatigue as compared to the pre-fatigue condition (Figure 13). There was no difference in the width of the medial joint space pre-fatigue to post-fatigue during the unstressed condition. The stress by fatigue interaction was statically significant ($F_{(29,1)} = 4.2$, $p = 0.048$), with an observed power of 0.513. The mean width of the medial joint space in an unstressed position pre-fatigue was 2.8 ± 0.1 mm (95% CI of 2.6 mm to 2.9 mm). The mean width of the medial joint space in an unstressed position post-fatigue was 2.8 ± 0.1 mm (95% CI of 2.6 mm to 3.0 mm). The mean width of the medial joint space in a stressed position pre-fatigue was 3.5 ± 0.1 mm (95% CI of 3.3 mm to 3.8 mm). The mean width of the medial joint space in a stressed position post-fatigue was 3.7 ± 0.1 mm (95% CI of 3.4 mm to 3.9 mm).

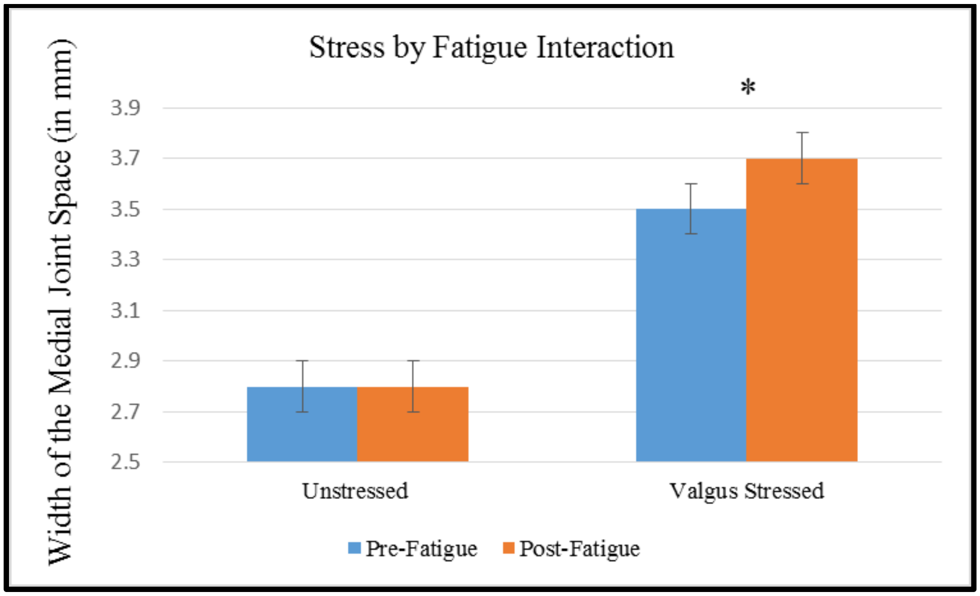

Figure 13: Stress by Fatigue Interaction. Width of the medial joint space in millimeters in unstressed and stressed positions pre-fatigue compared to post-fatigue. Error bars represent standard error. * $p < 0.05$.

Stress * Test Interaction. The stress by test interaction was not statistically significant ($F_{(29,1)} = 2.4$, $p = 0.132$), with an observed power of 0.323 (Figure 14). The mean width of the medial joint space in an unstressed position during the clinical valgus stress test was 2.8 ± 0.1 mm (95% CI of 2.6 mm to 3.0 mm). The mean width of the medial joint space in an unstressed position during the weighted valgus stress test was 2.8 ± 0.1 mm (95% CI of 2.6 mm to 2.9 mm). The mean width of the medial joint space in a stressed position during the clinical valgus stress test was 3.6 ± 0.1 mm (95% CI of 3.4 mm to 3.9 mm). The mean width of the medial joint space in a stressed position during the weighted valgus stress test 3.6 ± 0.1 mm (95% CI of 3.3 mm to 3.8 mm).

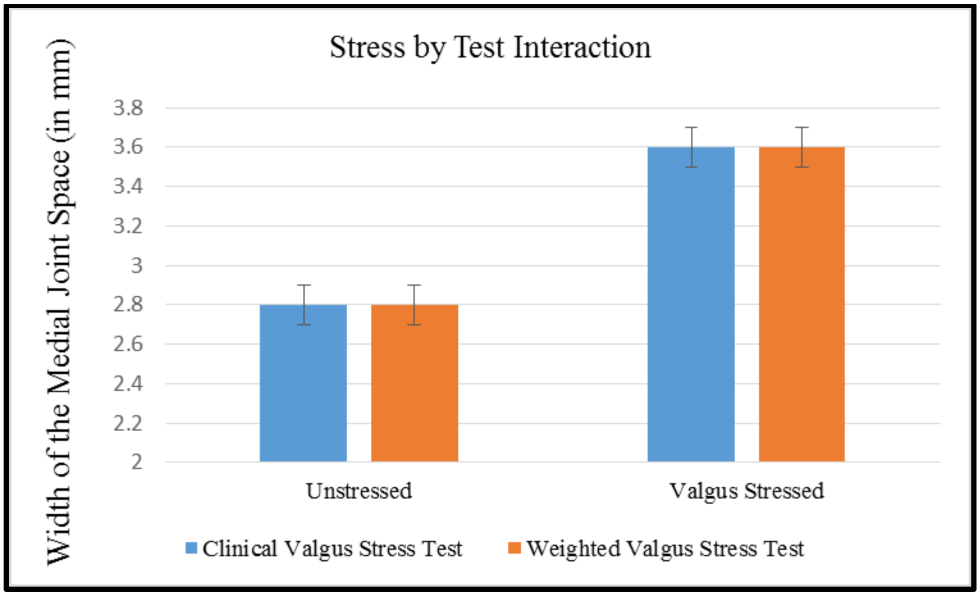

Figure 14: Stress by Test Interaction. Width of the medial joint space in millimeters in unstressed and stressed positions comparing clinical and weighted valgus stress tests. Error bars represent standard error.

Fatigue * Test Interaction. The fatigue by test interaction was not statistically significant ($F_{(29,1)} = 0.1$, $p = 0.825$), with an observed power of 0.055 (Figure 15). The mean width of the medial joint space pre-fatigue during the clinical valgus stress test was 3.2 ± 0.1 mm (95% CI of 3.0 mm to 3.4 mm). The mean width of the medial joint space post-fatigue during the clinical valgus stress test was 3.3 ± 0.1 mm (95% CI of 3.0 mm to 3.5 mm) (Figure 15). The mean width of the medial joint space pre-fatigue during the weighted valgus stress test was 3.1 ± 0.1 mm (95% CI of 2.9 mm to 3.3 mm). The mean width of the medial joint space post-fatigue during the weighted valgus stress test was 3.2 ± 0.1 mm (95% CI of 3.0 mm to 3.4 mm).

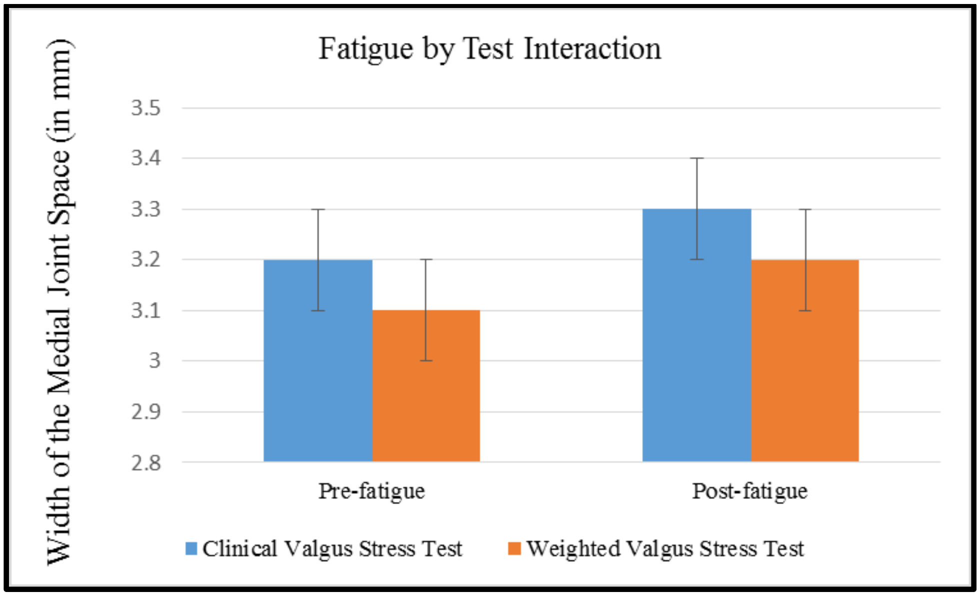

Figure 15: Fatigue by Test Interaction. Width of the medial joint space in millimeters in pre-fatigue and post-fatigue states comparing the clinical and weighted valgus stress tests. Error bars represent standard error.

Stress * Fatigue * Test Interaction. The stress by fatigue by test interaction was not statistically significant ($F_{(29,1)} = 0.5$, $p = 0.495$), with an observed power of 0.103 (Figure 16). The mean width of the medial joint space in an unstressed position during the clinical valgus stress test pre-fatigue was 2.8 ± 0.1 mm (95% CI of 2.6 mm to 3.0 mm). The mean width of the medial joint space in an unstressed position during the weighted valgus stress test pre-fatigue was 2.8 ± 0.1 mm (95% CI of 2.6 mm to 2.9 mm). The mean width of the medial joint space in an unstressed position during the clinical valgus stress test post-fatigue was 2.8 ± 0.1 mm (95% CI of 2.6 mm to 3.0 mm). The mean width of the medial joint space in an unstressed position during the weighted valgus stress test post-fatigue was 2.8 ± 0.1 mm (95% CI of 2.6 mm to 2.9 mm). The mean width of the medial joint space in a stressed position during the clinical valgus stress test pre-fatigue was 3.6 ± 0.1 mm (95% CI of 3.3 mm to 3.8 mm). The mean width of the medial joint space in a stressed position during the weighted valgus stress test pre-fatigue was

3.5 ± 0.1 mm (95% CI of 3.3 mm to 3.7 mm). The mean width of the medial joint space in a stressed position during the clinical valgus stress test post-fatigue was 3.7 ± 0.1 mm (95% CI of 3.5 mm to 3.9 mm). The mean width of the medial joint space in a stressed position during the weighted valgus stress test post-fatigue was 3.6 ± 0.1 mm (95% CI of 3.4 mm to 3.9 mm).

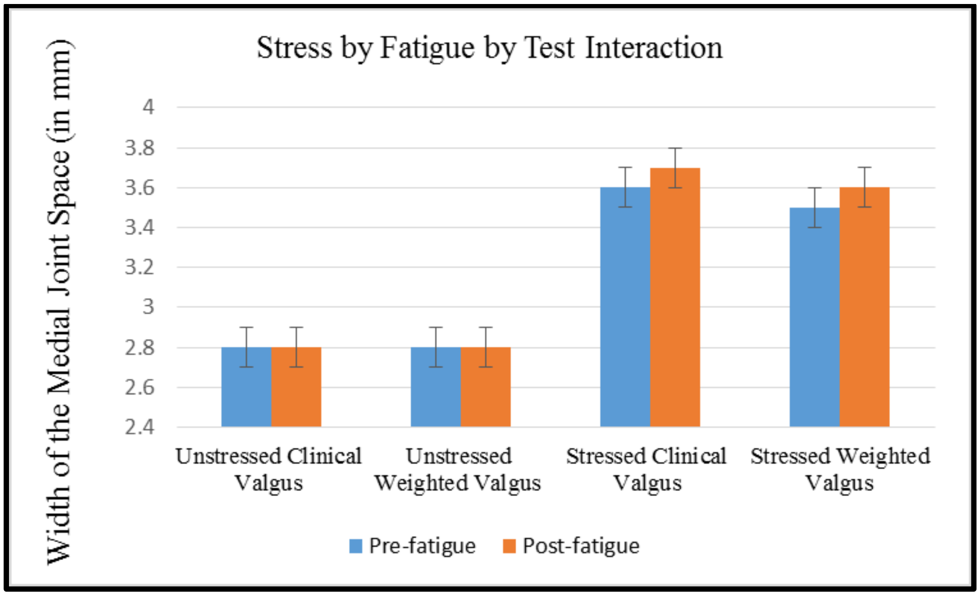

Figure 16: Stress by Fatigue by Test Interaction. Width of the medial joint space in millimeters in pre-fatigue and post-fatigue states comparing the clinical and weighted valgus stress tests in both unstressed and stressed conditions. Error bars represent standard error.

CHAPTER 5

DISCUSSION

The fatigue protocol led to a small (7.5%) but statistically significant decrease in force production as measured by handheld dynamometry (Figures 7 & 8). The alternative hypothesis that the width of the medial joint space during valgus stress tests will increase following the fatigue protocol was accepted. The width of the medial joint space increased during the valgus stress tests (Figure 10) and was greater after the fatigue protocol (Figure 11). The width of the medial joint space during valgus stress tests increased after the fatigue of the FPM (Figure 13). The increase was seen in the stressed condition, and not in the unstressed condition (Figure 13). Therefore the width of the medial joint space increases following FPM fatigue under stressed conditions.

The current study observed the FPM elbow stability decreased following the fatigue protocol, but it cannot be determined if the decreases were related to the muscular fatigue or changes within the elastic components of the muscle tendons during exercise. Interesting findings in a study observing changes in stiffness of the Achilles tendon, female participants reported a statistically significantly reduced tendon stiffness (536.2 ± 120.0 N/mm to 369.7 ± 91.7 N/mm; $p < 0.001$) within the tendon after the repetitive "toe jumping" while males reported no statistically significant difference (Joseph et al., 2014). Given the larger amount of females within the study, this could be a confounding variable. Ideally the effects of the study are due to muscle fatigue and the FPM fatigue can be proven to increase the width of the medial joint space, but further research on FPM fatigue should be conducted. A large limitation found during research was the need for differentiation between the elastic component of tendon and fatigue changes within the muscle.

Another limitation to the current study was the relatively low level of fatigue resulting from the fatigue protocol. A mean reduction of 7.5% in wrist flexion force production is relatively minimal. The level of fatigue observed in the current study could be consistent with the level of fatigue developed by moderate physical activity. Despite the low level of fatigue, increases in the width of the medial joint space post-fatigue with valgus loading were found. Therefore the changes in the elastic components of the FPM may have been the main change within this study due to the protocol acting more as a warm up for those muscles. The fatigue protocol mostly worked as simple exercises for many participants, measuring no decrease in wrist flexion force production. Increasing loading to bring the participant to failure of the desired task in future studies could help differentiate between the fatigue and elastic components.

The width of the medial joint space in the current study was much smaller than what has been reported in earlier studies. Ciccotti et al. (2014) reported the width of the medial joint space for the dominant arm 3.32 ± 0.07 mm at unstressed, 4.56 ± 1.10 mm under 150 N stress while evaluating 368 asymptomatic professional baseball pitchers' elbows using ultrasound. These measures were taken using the same ultrasound imaging technique and using the same points of reference for measuring the width of the medial joint space as the current study. The greater width of the medial joint space seen in the Ciccotti et al. (2014) study was likely due to differences in the study's demographics. The Ciccotti et al. (2014) study used all male professional baseball athletes compared to our 60% female population. The non-dominant measurements in their study are closer to the findings within the current study. The current study could be replicated using a similar baseball population to more accurately compare the ultrasound measures with the Ciccotti et al. (2014) study.

Another study was performed on high school baseball pitchers with and without elbow pain (Tajika et al., 2016). Tajika et al. (2016) had a demographic pool similar to the current study in height (172.3 ± 5.7 cm) and weight (65.8 ± 7.9 kg); however, the numbers are not very comparable to the current study. The possible reason for the width of the medial joint space differences is the measurement techniques were different. Within the current study the measurements were taken from the edge of the trochlea of the humerus and edge of the coronoid process of the ulna, but the study by Tajika et al. (2016) measured from the middle of the trochlea to the edge of the coronoid process. In the participants without pain (n = 75), Tajika et al. (2016) measured the width of the medial joint space in the dominant arm to be 4.6 ± 1.0 mm unstressed, and 5.9 ± 1.3 mm during weighted gravity stress. The same participants' non-dominant arms were measured as 4.3 ± 1.1 mm unstressed, and 5.2 ± 1.3 mm during weighted gravity stress (Tajika et al., 2016). While containing similar demographic data, this study's measurements are not comparable due to measurement technique. Further standardization of ultrasound procedures could benefit in comparing research.

Muscle Fatigue

Fatigue is a reduction in the force a muscle group can produce in a plane of movement (Blangsted et al., 2005). This change in force production can be seen with heavier resistance, shorter duration fatigue protocols (Wang et al., 2016) as well as lighter resistance repetitive fatigue protocols (Cowley & Gates, 2017). The fatigue levels reported within both studies were higher than the fatigue reported within the current study. Cowley & Gates (2017) used a repetitive fatigue protocol with the stopping point at RPE of >8 or when the participant was unable to complete the exercise. Their protocol produced a decrease of about 20% on maximal voluntary contractions ($p < 0.001$) (Cowley & Gates, 2017). The current study did not induce the desirable amount of fatigue like the pilot study or other fatigue studies. The desirable amount of fatigue for the current study was 15% based on pilot investigation, while actual study observations were a 7.5% decrease in force production. Despite not reaching the desirable fatigue, the FPM muscle force production did see a significant decrease. A protocol bringing the participants to exhaustion would have increased the validity of the current study.

The Borg CR-10 ratings of perceived exertion after each set of 30 repetitions were low (After: 1^{st} – 2.1, 2^{nd} – 2.3, 3^{rd} – 2.7) (Figure 9). These numbers are lower than previous studies' reported means for blue Therabands™, 3.8 ± 0.4 (L. L. Andersen et al., 2010). The percentage decrease in wrist flexion strength was also objectively low with a 7.5% decrease (22.6 ± 7.7 lbs. pre-fatigue to 20.9 ± 8.3 lbs. post-fatigue). A solution to the lack of fatigue could be a change of level on the Theraband™ from blue to heavier bands such as black, silver, or even gold based on either weight or initial wrist flexion strength ranges of participants. Regardless of lower perceived exertion ratings, the reported means were roughly between 30-40% of the participants' maximal voluntary contraction according to the lower perceived ratings when working at the lower end of the exertion scale (Pincivero et al., 2003).

In stronger participants it was common to notice an increase in wrist flexion strength after the first set, then a minimal gradual decrease by the end of the protocol. The participants that found the exercise to be too easy simply had the protocol act as a warm up exercise, which did not induce fatigue. This lack of true fatigue in some participants may have skewed some of the data within this study. The speed of the exercise was also a self-selected pace. Although instructed to go at a slow and controlled pace, some participants still performed the exercise very rapidly. The variability was limited by instructing participants after the first set to either slow down or speed up the repetitions, but the variability was still evident. Adding a metronome speed and taking the participants to exhaustion or failure for the exercise could increase the validity of this study.

Limitations

The results of the current study can only be applied to unimpaired elbows. Only healthy non-dominant elbows were tested to measure a baseline of what is normal. That baseline also demonstrates that the width of the medial joint space increases due to fatigue can be seen during stress US imaging. The throwing athlete may be affected differently, given that they throw often and use these muscles frequently. Therefore the current study observed what would be considered a normal non-dominant elbow, and can only be applied to that population.

The participants utilized in the current study did not have current or previous elbow pain. Our findings might differ if the investigation was repeated in participants with injured elbow. Injured participants would not perform as well during maximal voluntary contractions or endurance exercises (Glousman et al., 1992). The withholding effort of injured individuals means that the study would be less reliable in individuals with pain, due to the participant being unable to perform their full wrist flexion forces to measure fatigue (Glousman et al., 1992).

Using a clinical valgus stress test may lead to variability in stress of the medial elbow during the research testing. An elbow arthrometer was not used for this study, because devices were not available to us. This device would have allowed for the more graded application of valgus force. The study suggested, however, a consistent stress during the valgus stress, exhibiting the same standard error of the width of the medial joint space measurements as the weighted valgus stress test at ± 0.1 mm. The finding that the standard error and the range of measures are the same demonstrate consistency for the subjective pressure of the clinical valgus stress test, when compared to the objective nature of the weighted valgus stress test. Both stressed conditions have significant increases post-fatigue as well. The use of a clinical valgus stress test was not a true limitation to the study because of its consistency of force and measures.

With this study only measuring at about 30^{o} of elbow flexion, these findings cannot be applied to the throwing athlete due to arm position during competition. The study findings can be applied to sideline assessments for valgus stress tests, but not in greater ranges of motion (Edwards & Smith, 2013). Therefore testing in 30^{o} of elbow flexion was a minor limitation, as it narrowed the applicable uses for the current study. Further research could measure the width of the medial joint space changes at 90^{o} during the milking maneuver or the moving valgus stress test as well (O'Driscoll, Lawton, & Smith, 2005).

Pilot Study Observations

The pilot study only demonstrated an increase post-fatigue in width of the medial joint space during a clinical valgus stress test, but not during the weighted valgus stress test. Both the clinical valgus and weighted valgus tests had increases in post-fatigue measurements during the stresses for thesis research. The changes to utilizing an ankle weight compared to a dumbbell weight is likely the reason behind that observation. The ankle weight allowed a stress to be applied to the medial elbow with limited muscle activation (potential for guarding). The dumbbell being held by the participant involved muscle contraction likely creating a varus moment to balancing the valgus moment produced by the hand held weight. The gripping of the dumbbell could mean that minimal muscle activation could counter-act the effects of fatigue on the medial joint space unless there is sufficient fatigue. The use of ankle weights for the weighted valgus stress test is something to be taken into consideration when conducting further research.

Further Research

The current study reports a significant increase in the width of the medial joint space during a valgus stress after fatigue in an unimpaired elbow (0.2 mm increase, $p = 0.048$). Further research can branch into many different directions looking at different populations and greater fatigue protocol effects. Changing the population will lead to the larger variability of findings. Populations of healthy dominant elbows, throwing athletes (non-dominant and dominant arms), adolescents, elderly, injured elbows, and female versus male can be studied to greatly increase the applicable knowledge of fatigue of the FPM. Fatigue protocol changes can be done using heavier resistance protocols, or even setting percentage goals of reduced force production. Further research could be conducted testing the elbow with and without muscle activation to test the stabilization aspects of the FPM as well. Further research could be done bringing the muscle to exhaustion as well, which would mean that the decreases in stability would be directly related to fatigue and not the elastic components. The current study provides a baseline of what is normal for the width of the medial joint space of the elbow before and after minimally fatiguing exercise. Given that normal situations have been studied, abnormal can now be explored more reliably.

Conclusion

Fatigue of the FPM led to a significant increase in the width of the medial joint space of the elbow. This increase in the width of the medial joint space means there will be decreased medial elbow stability with fatigue. The decreased medial elbow stability following fatigue will place more stress on the UCL. The increased stress on the UCL could lead to an increase risk of injury to the UCL. There are further steps needed to explore this effect in throwing athletes, to establish the exact effect.

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APPENDIX A: LETTER FROM INSTITUTIONAL REVIEW BOARD

MARSHALL UNIVERSITY
www.marshall.edu

Office of Research Integrity
Institutional Review Board
One John Marshall Drive
Huntington, WV 25755

FWA 00002704

IRB1 #00002205
IRB2 #00003206

January 30, 2017

Mark Timmons, PhD
Marshall University, School of Kinesiology

RE: IRBNet ID# 868319-2
At: Marshall University Institutional Review Board #1 (Medical)

Dear Dr. Timmons:

Protocol Title:	[868319-2] The Assessment of Medial Elbow Stability.	
Expiration Date:	February 11, 2018	
Site Location:	MU	
Submission Type:	Continuing Review/Progress Report	APPROVED
Review Type:	Expedited Review	

The above study was approved for an additional 12 months by the Marshall University Institutional Review Board #1 (Medical) Chair. The approval will expire February 11, 2018. Since this approval is within 30 days of the expiration date, the fixed anniversary date of 2/11 was maintained. Continuing review materials should be submitted no later than 30 days prior to the expiration date.

If you have any questions, please contact the Marshall University Institutional Review Board #1 (Medical) Coordinator Trula Stanley,MA, CIC at (304) 696-7320 or stanley@marshall.edu. Please include your study title and reference number in all correspondence with this office.

APPENDIX B: INFORMED CONSENT

Informed Consent to Participate in a Research Study

Assessment of Medial Elbow Stability.

Mark K Timmons PhD ATC, Principal Investigator

Marshall University IRB	
Approved on:	1-30-17
Expires on:	2-11-18
Study number:	868319

Introduction

You are invited to be in a research study. Research studies are designed to gain scientific knowledge that may help other people in the future. You may or may not receive any benefit from being part of the study. There may also be risks associated with being part of research studies. If there are any risks involved in this study then they will be described in this consent. Your participation is voluntary. Please take your time to make your decision, and ask your research doctor or research staff to explain any words or information that you do not understand.

Why Is This Study Being Done?

The purpose of this study is to increase the understanding of 3 methods of measuring elbow stability and how fatigue of the forearm muscle effects elbow stability.

How Many People Will Take Part In The Study?

About 30 people will take part in this study. A total of 50 subjects are the most that would be able to enter the study.

What Is Involved In This Research Study?

During the study you will first fill out a questionnaire about your upper extremity, then the researcher will perform a brief examination of your arm. After the examination the researcher will use an ultrasound machine to make several images of the elbow and shoulder of the arm that you write with. During the ultrasound imaging you will need to wear a sleeveless or tank top shirt. During the ultrasound imaging you will be asked to lay down and your arm will be placed in several positions, while the researchers move your arm into several different positions. You will also be asked to perform several contractions of your arm muscles so that we can test your strength. After the ultrasound imaging is complete, the researcher will place several small sensors around your shoulders. These sensors will measure your motion and muscle activity. The research will then ask you to several wrist exercises while the motion of your shoulder and activity of your muscles are measured. You will hold a small weight in your hands while you do these exercises. The questionnaire, shoulder examination, motion testing and ultrasound imaging will take about 60 minutes to complete.

How Long Will You Be In The Study?

You will be in the study for one testing sessions that will take about 60 minutes to complete.

You can decide to stop participating at any time. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff to discuss what follow up care and testing could be most helpful for you.

Subject's Initials ________

The study principal investigator may stop you from taking part in this study at any time if he/she believes it is in your best interest; if you do not follow the study rules; or if the study is stopped.

What Are The Risks Of The Study?

Being in this study involves some risk to you. You should discuss the risk of being in this study with the study staff.

You should talk to your study doctor about any side effects that you have while taking part in the study.

Risks and side effects related to the testing session include: increased shoulder pain, muscle soreness, muscle fatigue and reduced forearm strength. These risks and side effects are temporary and are no greater than the risks associated with any physical exercise program. These side effects can be reduced by stretching exercises, and applying either moist heat or ice. **If you experience pain that you would describe as being more than 7 out of 10 you should stop the testing session contact your doctor.**

There may also be other side effects that we cannot predict. You should tell the research staff about all the medications, vitamins and supplements you take and any medical conditions you have. This may help avoid side effects, interactions and other risks. There are no funds available for compensation for any injury that occurs as a result of your participation in this study.

Are There Benefits To Taking Part In The Study?

If you agree to take part in this study, there may or may not be direct benefit to you. We hope the information learned from this study will benefit other people in the future. The benefits of participating in this study may be: You will gain information about the function of your shoulder.

What Other Choices Are There?

You do not have to be in this study.

What About Confidentiality?

We will do our best to make sure that your personal information is kept confidential. However, we cannot guarantee absolute confidentiality. Federal law states that we must keep your study records private. Nevertheless, certain people other than your researchers may also need to see your study records. By law, anyone who looks at your records must keep them completely confidential.

Those who may need to see your records are:

- Certain university and government people who need to know more about the study. For example, individuals who provide oversight on this study may need to look at your records. These include the Marshall University Institutional Review Board (IRB) and the Office of Research Integrity (ORI). Other individuals who may look at your records include: *the federal Office of Human Research Protection*, This is done to make sure that we are doing the study in the right way. They also need to make sure that we are protecting your rights

Subject's Initials ________

and your safety.

If we publish the information we learn from this study, you will not be identified by name or in any other way.

What Are The Costs Of Taking Part In This Study?

There are no costs to you for taking part in this study. All the study costs, including any study medications and procedures related directly to the study, will be paid for by the study. Costs for your regular medical care, which are not related to this study, will be your own responsibility.

Will You Be Paid For Participating?

You will not be paid if you decide to participate in this study.

Who Is Funding This Study?

This study is being sponsored by Marshall University School of Kinesiology

What Are Your Rights As A Research Study Participant?

Taking part in this study is voluntary. You may choose not to take part or you may leave the study at any time. Refusing to participate or leaving the study will not result in any penalty or loss of benefits to which you are entitled. If you decide to stop participating in the study we encourage you to talk to the investigators or study staff first to learn about any potential health or safety consequences.

Whom Do You Call If You Have Questions Or Problems?

For questions about the study or in the event of a research-related injury, contact the study investigator, Mark K Timmons ATC, PhD at (304)696-2925. You should also call the investigator if you have a concern or complaint about the research.

For questions about your rights as a research participant, contact the Marshall University IRB#1 Chairman Dr. Henry Driscoll or ORI at (304) 696-7320. You may also call this number if:

- You have concerns or complaints about the research.
- The research staff cannot be reached.
- You want to talk to someone other than the research staff.

You will be given a signed and dated copy of this consent form.

Subject's Initials ________

SIGNATURES

You agree to take part in this study and confirm that you are 18 years of age or older. You have had a chance to ask questions about being in this study and have had those questions answered. By signing this consent form you are not giving up any legal rights to which you are entitled.

____
Subject Name (Printed)

____ ____________________
Subject Signature Date

____ ____________________
Person Obtaining Consent Date

____ ____________________
Principal Investigator Date

Subject's Initials ________

APPENDIX C: QDASH QUESTIONNAIRE

Subject Number
Date

Initial Visit

THE *Quick*DASH

OUTCOME MEASURE

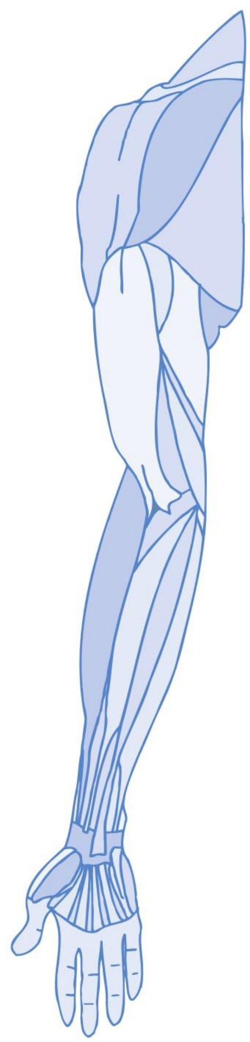
INSTRUCTIONS

This questionnaire asks about your symptoms as well as your ability to perform certain activities.

Please answer *every question*, based on your condition in the last week, by circling the appropriate number.

If you did not have the opportunity to perform an activity in the past week, please make your *best estimate* of which response would be the most accurate.

It doesn't matter which hand or arm you use to perform the activity; please answer based on your ability regardless of how you perform the task.



*Quick*DASH

Please rate your ability to do the following activities in the last week by circling the number below the appropriate response.

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. Open a tight or new jar.	1	2	3	4	5
2. Do heavy household chores (e.g., wash walls, floors).	1	2	3	4	5
3. Carry a shopping bag or briefcase.	1	2	3	4	5
4. Wash your back.	1	2	3	4	5
5. Use a knife to cut food.	1	2	3	4	5
6. Recreational activities in which you take some force or impact through your arm, shoulder or hand (e.g., golf, hammering, tennis, etc.).	1	2	3	4	5

	NOT AT ALL	SLIGHTLY	MODERATELY	QUITE A BIT	EXTREMELY
7. During the past week, *to what extent* has your arm, shoulder or hand problem interfered with your normal social activities with family, friends, neighbours or groups?	1	2	3	4	5

	NOT LIMITED AT ALL	SLIGHTLY LIMITED	MODERATELY LIMITED	VERY LIMITED	UNABLE
8. During the past week, were you limited in your work or other regular daily activities as a result of your arm, shoulder or hand problem?	1	2	3	4	5

Please rate the severity of the following symptoms in the last week. *(circle number)*	NONE	MILD	MODERATE	SEVERE	EXTREME
9. Arm, shoulder or hand pain.	1	2	3	4	5
10. Tingling (pins and needles) in your arm, shoulder or hand.	1	2	3	4	5

	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	SO MUCH DIFFICULTY THAT I CAN'T SLEEP
11. During the past week, how much difficulty have you had sleeping because of the pain in your arm, shoulder or hand? *(circle number)*	1	2	3	4	5

*Quick***DASH DISABILITY/SYMPTOM SCORE** = $\left(\left[\frac{\text{sum of n responses}}{n}\right] - 1\right) \times 25$, where n is equal to the number of completed responses.

A *Quick*DASH score may not be calculated if there is greater than 1 missing item.

*Quick*DASH

WORK MODULE (OPTIONAL)

The following questions ask about the impact of your arm, shoulder or hand problem on your ability to work (including homemaking if that is your main work role).

Please indicate what your job/work is:____

❒ I do not work. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week.

Did you have any difficulty:	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for your work?	1	2	3	4	5
2. doing your usual work because of arm, shoulder or hand pain?	1	2	3	4	5
3. doing your work as well as you would like?	1	2	3	4	5
4. spending your usual amount of time doing your work?	1	2	3	4	5

SPORTS/PERFORMING ARTS MODULE (OPTIONAL)

The following questions relate to the impact of your arm, shoulder or hand problem on playing *your musical instrument or sport or both*. If you play more than one sport or instrument (or play both), please answer with respect to that activity which is most important to you.

Please indicate the sport or instrument which is most important to you:____________________________

❒ I do not play a sport or an instrument. (You may skip this section.)

Please circle the number that best describes your physical ability in the past week.

Did you have any difficulty:	NO DIFFICULTY	MILD DIFFICULTY	MODERATE DIFFICULTY	SEVERE DIFFICULTY	UNABLE
1. using your usual technique for playing your instrument or sport?	1	2	3	4	5
2. playing your musical instrument or sport because of arm, shoulder or hand pain?	1	2	3	4	5
3. playing your musical instrument or sport as well as you would like?	1	2	3	4	5
4. spending your usual amount of time practising or playing your instrument or sport?	1	2	3	4	5

SCORING THE OPTIONAL MODULES: Add up assigned values for each response; divide by 4 (number of items); subtract 1; multiply by 25.
An optional module score may not be calculated if there are any missing items.

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APPENDIX D: DATA COLLECTION FORM

Subject ID number: ______________________ **Date: ____/____/____**

Initial Data Collection Forms

Procedure Checklist

Assessment of Medial Elbow Stability

1. Inclusion & exclusion criteria
   a. Eligibility Screening exam
2. Subject Informed Consent
   a. Read, discuss, ask questions, sign
3. General Questions- Eligibility and Screening
   a. Intake information
   b. Patient reported outcomes (DASH)
   c. Height , Weight
4. Clinical Evaluation
5. Range of motion
   a. Flexion / extension
   b. Pronation / Supination
6. Strength Procedure
   a. Elbow flexion
   b. Elbow extension
   c. Grip strength
7. Ultrasound Imaging-
   a. Medial elbow rest
   b. Medial elbow stress 1
   c. Medial elbow stress 2
   d. Medial elbow stress 3
   e. Wrist flexor mass long
   f. Wrist extensor mass transverse
   g. GIRD
8. Wrist flexor fatigue protocol
   a. RPE
9. Strength Procedure, post exercise
   a. Elbow flexion
   b. Elbow extension
   c. Grip strength
10. Ultrasound Imaging
    a. Medial elbow rest
    b. Medial elbow stress 1

Inclusion criteria

At least 18 years old
Ability to sit still for up to 5 minutes

Exclusion criteria

History of shoulder, elbow or arm injury during the previous 2 years
History of fracture or surgery to the trunk or upper extremity
Upper extremity or throwing athletes
Systemic musculoskeletal disease
Elbow pain $\geq$2/10
Greater than 50% loss of shoulder or elbow range of motion

Subject meets inclusion/exclusion criteria (circle one):

1= Yes, continue **2= No**, stop

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Subject ID number: ______________________ **Date:** ____/____/____

Research Study Questionnaire
Participant completes:

DOB (mm/dd/yy): ____/___/____

Age: _____ (years) **Sex:** 1 = Female 2 = Male

1. **Do you have any systemic musculoskeletal disease (like Rheumatoid Arthritis)?**
   (Circle One) 1 = Yes If yes, please list____________________________
   2 = No
2. **Do you currently have or have had elbow pain in the last 6 months?**
   (Circle One) 1 = Yes 2 = No

   If yes, how would you rate the pain?
   (0 = no pain at all, 10 = the worst imaginable pain) _____________
3. **Which shoulder is your dominant side?** Which hand do your write with or throw a ball with?
   1 = Right
   2 = Left
   3 = Ambidextrous
4. **How would you rate your elbow today (as "a percentage of normal")?**
   (0% - 100% with 100% being normal) **= _______%**
5. **Have you had elbow surgery?** 1 = Yes 2 = No
6. **Do you have a known elbow problem/ pathology?**
   1 = Yes 2 = No
   a. If yes, which elbow? 1 = Right 2 = Left 3= Both
   b. If yes, have you sought treatment for this problem
      1 = Yes 2 = No
   c. If yes, when did your elbow pain start?
      1 ____ Less than 6 weeks ago
      2 ____ 6-12 weeks ago
      3 ____ More than 12+ weeks ago
      4 ____ I do not have shoulder pain
   d. If yes, please describe: ____
      ____
      ____
      ____
      ____

Subject ID number: ______________________ **Date:** ____/____/____

Screening Exam

Research Team completes

Subject height: ___________(cm) **Subject weight:**________________(Kg)

Shoulder ROM:

Elbow Flexion	____________
Elbow Extension	____________
Pronation	____________
Supination	____________
Wrist Flexion	____________
Wrist Extension	____________

Shoulder ROM:

External Rotation	____________
Internal Rotation	____________
Abduction	____________
Flexion	____________

Special Tests:			**End Feel**
Elbow Valgus	+	-	______________________________
Milking Maneuver	+	-	______________________________

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Subject ID number: ______________________ **Date:** ____/____/____

Participant's Physical Measures

Research Team completes

Pre Exercise

Force, and Pain

	Pre Fatigue		Post Fatigue					
Trial			1		2		3	
	Pain	Force	Pain	Force	Pain	Force	Pain	Force
Wrist flex 1								
Wrist flex 2								
Wrist flex 3								
Wrist ext 1								
Wrist ext 2								
Wrist ext 3								
Grip Strength position 2 1								
Grip Strength position 2 2								
Grip Strength position 2 3								
Grip Strength position 3 1								
Grip Strength position 3 2								
Grip Strength position 3 3								

Perceive Exertion

	Band Color	#reps	Exertion
Bout 1	________	______	____________
Bout 2	________	______	____________
Bout 3	________	______	____________
Bout 4	________	______	____________
Bout 5	________	______	____________

Subject ID number: ______________________ **Date:** ____/____/____

US Imaging of the Medial Elbow

File name (on US machine): _____________ Examiner Andrew DeMoss

Stress Test (UNSTRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (UNSTRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (UNSTRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Post Exercise File name (on US machine): _____________

Stress Test (UNSTRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (UNSTRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Subject ID number: ______________________ **Date:** ____/____/____

US Imaging of the Medial Elbow

File name (on US machine): _____________ Examiner Nathaniel Millard

Stress Test (UNSTRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (UNSTRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (UNSTRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Post Exercise File name (on US machine): _____________

Stress Test (UNSTRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (UNSTRESSED):

Image 1 **Image 2**

______ _____ ______ _____

Stress Test (STRESSED):

Image 1 **Image 2**

______ _____ ______ _____

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APPENDIX E: RANGE OF MOTION (ROM) USING A GONIOMETER

Range of Motion (ROM) using a Goniometer (Norkin & White, 2003)				
Motion	Fulcrum	Proximal Arm	Distal Arm	Normal ROM
Shoulder Complex Flexion	Over the lateral aspect of the greater tubercle	Parallel to the midaxillary line of the thorax	Lateral epicondyle of the humerus	180°
Shoulder Complex Abduction	Close to the anterior aspect of the acromial process	Align parallel with the midline of the anterior aspect of sternum	Anterior midline of the humerus	180°
Elbow Flexion	Over the lateral epicondyle of the humerus	Aligned with the midline of the humerus	Aligned with the lateral midline of the forearm	140°-150°
Elbow Extension	Over the lateral epicondyle of the humerus	Aligned with the midline of the humerus	Aligned with the lateral midline of the forearm	0°
Pronation	Laterally and proximally to the ulnar styloid process	Parallel to the anterior midline of the humerus	Dorsal aspect of the forearm, just proximal to the styloid processes of the radius and ulna	80°
Supination	Laterally and proximally to the ulnar styloid process	Parallel to the anterior midline of the humerus	Ventral aspect of the forearm, just proximal to the styloid processes of the radius and ulna	80°
Wrist Flexion	On the lateral aspect of the triquetrum	Lateral midline of the ulna	Lateral midline of the 5^{th} metacarpal	60°
Wrist Extension	On the lateral aspect of the triquetrum	Lateral midline of the ulna	Lateral midline of the 5^{th} metacarpal	60°

Table 2: Range of Motion (ROM) using a Goniometer.

Range of Motion (ROM) using a Digital Inclinometer (Kolber & Hanney, 2012)			
Motion	Position of Participant	Inclinometer Placement	Normal ROM
Shoulder Internal Rotation	Participant's shoulder is in 90° of abduction and the elbow is flexed to 90°, while the wrist is in a neutral position.	Distal forearm, just proximal to the wrist	70°
Shoulder External Rotation	Participant's shoulder is in 90° of abduction and the elbow is flexed to 90°, while the wrist is in a neutral position.	Distal forearm, just proximal to the wrist	90°

Table 2 Continued: Range of Motion (ROM) using a Goniometer.